

Safety Standards

of the
Nuclear Safety Standards Commission (KTA)

KTA 3203 (2017/11)

Surveillance of the Irradiation Behaviour of Reactor Pressure Vessel Materials of LWR Facilities

(Überwachung des Bestrahlungsverhaltens von Werkstoffen der Reaktordruckbehälter von Leichtwasserreaktoren)

Previous versions of this Safety Standard were issued
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If there is any doubt regarding the information contained in this translation, the German wording shall apply.

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Surveillance of the Irradiation Behaviour
of Reactor Pressure Vessel Materials of LWR Facilities

KTA 3203

CONTENTS

Fundamentals.....	5
1 Scope.....	5
2 Definitions	5
3 General Principles.....	6
3.1 Purpose of the irradiation surveillance program	6
3.2 Necessity of implementing an irradiation surveillance program	6
4 Irradiation surveillance program.....	8
4.1 Irradiation plan	8
4.2 Requirements for capsules containing irradiation exposure specimens	8
4.3 Location of capsules in the RPV	9
4.4 Number of specimen sets	9
4.5 Point in time of insertion and withdrawal of specimen sets.....	9
5 Selection of materials for irradiation specimens	9
5.1 Selection criteria	9
5.2 Test coupon	9
5.3 Material specimens and reserve material	9
5.4 Specimen orientation and location.....	9
6 Testing and evaluation.....	9
6.1 General	10
6.2 Irradiation temperature.....	10
6.3 Neutron fluence determination	10
6.4 Mechanical tests	10
7 Retention of specimens	12
8 Documentation.....	12
Annex A: Regulations and literature referred to in this Safety Standard.....	13
Annex B: Data for the determination and criteria for use of the RT_{limit} curve.....	15
Annex C: Changes with respect to previous edition 2001-06 and explanations (informative)	18

PLEASE NOTE: Only the original German version of this Safety Standard represents the joint resolution of the 35-member Nuclear Safety Standards Commission (Kerntechnischer Ausschuss, KTA). The German version was made public in the Federal Gazette (Bundesanzeiger) on May 17th, 2018. Copies of the German versions of the KTA Safety Standards may be mail-ordered through the Wolters Kluwer Deutschland GmbH (info@wolterskluwer.de). Downloads of the English translations are available at the KTA website (<http://www.kta-gs.de>).

All questions regarding this English translation should please be directed to the KTA office:

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Comments by the editor:

Taking into account the meaning and usage of auxiliary verbs in the German language, in this translation the following agreements are effective:

shall	indicates a mandatory requirement,
shall basically	is used in the case of mandatory requirements to which specific exceptions (and only those!) are permitted. It is a requirement of the KTA that these exceptions - other than those in the case of shall normally - are specified in the text of the safety standard,
shall normally	indicates a requirement to which exceptions are allowed. However, the exceptions used, shall be substantiated during the licensing procedure,
should	indicates a recommendation or an example of good practice,
may	indicates an acceptable or permissible method within the scope of this safety standard.

Fundamentals

(1) The safety standards of the Nuclear Safety Standards Commission (KTA) have the objective to specify safety-related requirements, compliance of which provides the necessary precautions in accordance with the state of the art in science and technology against damage arising from the construction and operation of the facility (Sec. 7 para. 2 subpara. 3 Atomic Energy Act - AtG) in order to achieve the fundamental safety functions specified in the Atomic Energy Act and the Radiological Protection Ordinance (StrlSchV) and further detailed in the Safety Requirements for Nuclear Power Plants (SiAnf) as well as in the Interpretations on the Safety Requirements for Nuclear Power Plants.

(2) No. 2.1 of the Safety Requirements for Nuclear Power Plants, among other things, sets stringent requirements for the quality assurance and reliability of manufacturing. In no. 3.1 furthermore the use of qualified materials and manufacturing as well as the assurance and maintenance of the quality features during manufacturing is required. Safety requirement no. 3.4 (1) requires, among other things, that the reactor coolant pressure boundary shall be designed, located and operated such that the occurrence of rapidly propagating cracks and of brittle fracture need not be postulated. According to the requirement 5 (3) a documentation shall be established showing that the current condition of the safety-relevant measures and equipment fulfils the applicable requirements. Sub-para 3.2 (3) of Interpretation I-2 requires a monitoring program with suspended accelerated irradiation capsules to characterize the material properties changed due to irradiation. KTA safety standard 3203 defines provisions to be made to meet these requirements within their scope of application. For primary circuit components the stipulations of the aforementioned safety requirements are defined to comprise the following KTA safety standards.

KTA 3201.1 Materials and Product Forms,

KTA 3201.2 Design and Analysis,

KTA 3201.3 Manufacture,

KTA 3201.4 Inservice Inspections and Operational Monitoring.

and

KTA 3206 Break Preclusion Verifications for Pressure-Retaining Components in Nuclear Power Plants

(3) In particular, KTA safety standard 3203 defines requirements to be met regarding the monitoring of reactor pressure vessel (RPV) materials behaviour under the effects of neutron irradiation, especially with respect to the:

- performance and evaluation of irradiation surveillance programs,
- determination of neutron fluence,
- determination of the irradiation temperature,
- retention of specimens,
- documentation.

(4) The irradiation surveillance program especially serves to determine, by means of accelerated irradiation specimen capsules, the strength and toughness properties of base and weld materials in the core beltline region of the RPV as a function of defined neutron irradiation, and to confirm or define anew the location of the fracture toughness curve to be used as laid down in the brittle fracture analysis to KTA 3201.2.

1 Scope

This safety standard shall apply to the monitoring of irradiation behaviour of belt-line materials in the RPV pressure-retaining walls of light-water reactors.

2 Definitions

(1) Lead factor

The lead factor is the ratio of the neutron fluences (for neutron energies $E > 1$ MeV) of the irradiated specimens in the capsule to the maximum irradiated region of the ferritic internal RPV wall subject to the same irradiation time.

(2) Limit value of the reference temperature (RT_{limit})

The limit value of the reference temperature (RT_{limit}) is the highest adjusted reference temperature on which the proof of equivalent safety margin against brittle fracture is based.

(3) Core belt line region

The core belt line region is that wall area of the RPV subjected to irradiation which directly surrounds the active part of the reactor core (effective height of that part of the fuel rods filled with fuel), as well as adjacent regions which, as a result of the pre-calculated increase in reference temperature, have to be considered in the selection of the materials to be monitored.

(4) Assessment fluence (AF)

The assessment fluence is the neutron fluence used in the assessment against brittle fracture and for which the result of the assessment is valid.

(5) NDT temperature

The NDT (Nil Ductility Transition) temperature is the highest temperature at which a test specimen will fail in drop-weight testing.

(6) Neutron fluence (Φ)

The neutron fluence is the neutron flux density integrated over the irradiation time.

(7) Neutron flux density (ϕ)

The neutron flux density is the quotient of the number of neutrons of a defined energy level which in a certain time interval enter a small sphere around the spatial point considered, and of the product of the cross-sectional area of this sphere and the time interval. The neutron flux density is identical to the product of the neutron number density and the average velocity of the neutrons.

(8) Neutron spectrum

The neutron spectrum is the distribution of the neutron flux density as a function of the neutron energy. In general, the neutron spectrum is presented as groups assigned to specific energy intervals.

(9) Reference temperature RT_{NDT}

The reference temperature to the RT_{NDT} concept is established as follows:

- Determine a temperature T_{NDT} that is at or above the nil-ductility transition temperature by drop-weight tests.
- At a temperature not greater than $T_{\text{NDT}} + 33$ K each specimen of the notched-bar impact test (transverse specimen with V-notch) shall normally exhibit at least 0.9 mm lateral expansion and not less than 68 J impact energy. When these requirements are met, T_{NDT} is the reference temperature RT_{NDT} .
- In the event that the requirements of (b) above are not met, conduct additional notched-bar impact tests (transverse specimen with V-notch) in groups of three specimens to determine the temperature T_{KV} at which they are met. In this case the reference temperature $RT_{\text{NDT}} = T_{\text{KV}} - 33$ K. Thus, the reference temperature RT_{NDT} is the higher of T_{NDT} and $T_{\text{KV}} - 33$ K.
- When a notched-bar impact test has not been performed at $T_{\text{NDT}} + 33$ K, or when the notched-bar impact test does not exhibit a minimum of 68 J and 0.9 mm lateral expansion, a temperature representing a minimum impact energy

gy of 68 J and 0.9 mm lateral expansion shall normally be obtained from the impact-energy versus temperature curve and the lateral expansion versus temperature curve developed from the minimum values obtained from all specimens.

(10) Reference temperature RT_{NDT} , adjusted (RT_{NDTj})

This means the reference temperature as adjusted in the RT_{NDT} concept for irradiation effects by adding to the reference temperature of the unirradiated material the transition temperature shift ΔT_{41} to obtain:

$$RT_{NDTj} = RT_{NDT} + \Delta T_{41} \quad (2-1)$$

(11) Directly determined reference temperature RT_{T0} .

This means the reference temperature RT_{T0} as derived in the master curve concept from the reference temperature T_0 of the irradiated RPV material to obtain:

$$RT_{T0} = T_0 + 19.4 \text{ K} + M \quad (2-2)$$

The temperature allowance M considers the influence including the statistical variance of the type of specimen, type of material (base metal or weld metal), material variability, thickness and number of specimens on T_0 .

(12) Reference temperature RT_{T0} , adjusted (RT_{T0j})

This means the reference temperature as adjusted in the master curve concept for irradiation effects from the reference temperature T_{0u} to obtain:

$$RT_{T0j} = T_{0u} + k \cdot \Delta T_{41} + 19.4 \text{ K} + M \quad (2-3)$$

The temperature allowance M considers the influence including the statistical variance of the type of specimen, type of material (base metal or weld metal), material variability, thickness and number of specimens on T_0 .

The factor k describes the correlation between the transition temperature shift ΔT_{41} and transition temperature shift ΔT_0 of the master curve [1]. For German RPV materials a value $k = 1.0$ [2] applies.

(13) Reference temperature T_0 , irradiated condition

The reference temperature T_0 is the temperature determined to ASTM E1921 for the irradiated condition within the master curve concept.

(14) Reference temperature T_0 , unirradiated condition (T_{0u})

The reference temperature T_{0u} is the temperature determined to ASTM E1921 for the unirradiated condition within the master curve concept.

(15) Authorized inspector

The authorized inspector for the tests and inspections to be conducted in accordance with this safety standard is the authorized inspector called in by the licensing or supervisory authority pursuant to Section 20 of the Atomic Energy Act. The inspections/reviews required by this safety standard shall be performed on the basis of applications made by the competent authority.

(16) Transition-temperature shift (ΔT_{41})

The transition-temperature shift ΔT_{41} is the difference in the index temperatures for the best-fit (average) Charpy curve measured before and after irradiation of specimens at an impact energy of 41 J.

3 General Principles

3.1 Purpose of the irradiation surveillance program

(1) Specimens of the original ferritic materials shall be subject to accelerated irradiation in capsules inside the reactor

pressure vessel to experimentally verify the tensile and fracture toughness properties of the RPV material during operation up to the assessment fluence.

(2) By means of the results obtained within the irradiation program the location of the fracture toughness curve to be used within the brittle fracture analysis to KTA 3201.2 shall be confirmed or be determined anew either

- a) indirectly by using accelerated-irradiation impact specimens for determining the transition temperature shift ΔT_{41} , or
- b) directly by using accelerated-irradiation fracture toughness specimens for determining the reference temperature T_0 to the master curve concept to ASTM E1921.

(3) The location of the fracture toughness curve shall be determined by means of the reference temperature RT_{NDTj} using the transition temperature shift ΔT_{41} .

(4) Alternatively to the reference temperature RT_{NDTj} the use of the reference temperature RT_{T0} or RT_{T0j} is permitted. The temperature allowance M shall be determined appropriately in dependence of the governing variables and their statistical variance and be justified.

Notes:

(1) The alternative use of the reference temperature T_0 of the master curve concept increased by 19.4 K to determine the location of the fracture toughness curve is described in the Code Cases N-851 (Section XI) and N-631 (Section III) of the ASME Code. Information on the use of the master curve concept within a deterministic brittle fracture analysis and for the determination of a suitable temperature allowance M can be found e.g. in IAEA Technical Reports Series No. 429.

(2) Further information of the use of the master curve concept can be found e.g. in [3] to [9].

3.2 Necessity of implementing an irradiation surveillance program

(1) At a neutron fluence of less than $1 \cdot 10^{17} \text{ cm}^{-2}$ (for neutron energies $E > 1 \text{ MeV}$) in the maximum irradiated region of the ferritic inner wall of the RPV, no influence of radiation on the tensile and fracture toughness properties shall be considered in the proof of safety against brittle fracture. For this reason, no irradiation surveillance program is required.

(2) At a neutron fluence equal to or greater than $1 \cdot 10^{17} \text{ cm}^{-2}$ and equal to or less than $1 \cdot 10^{19} \text{ cm}^{-2}$ (for neutron energies $E > 1 \text{ MeV}$) in the maximum irradiated region of the ferritic inner wall of the RPV, the proof of safety against brittle fracture to KTA 3201.2, section 7.9 shall be based on the limit value of the reference temperature $RT_{\text{limit}} = 40 \text{ }^\circ\text{C}$ as per **Figure 3-1**. The adherence to the limit value RT_{limit} shall be confirmed using RT_{NDTj} or RT_{T0} or RT_{T0j} as a result of an irradiation program in accordance with **Table 3-1**, **Table 3-2** or **Table 3-3** respectively. The adjusted reference temperature RT_{NDTj} or RT_{T0} or RT_{T0j} thus determined may be taken for the proof of safety against brittle fracture alternatively to the value of RT_{limit} .

(3) At a neutron fluence greater than $1 \cdot 10^{19} \text{ cm}^{-2}$ (for neutron energies $E > 1 \text{ MeV}$) in the maximum irradiated region of the ferritic inner wall of the RPV, the proof of safety against brittle fracture to KTA 3201.2, section 7.9 shall be based on the limit value of the reference temperature RT_{limit} as per **Figure 3-1**. The adherence to the limit value RT_{limit} shall be confirmed to cover RT_{NDTj} or RT_{T0} or RT_{T0j} as a result of an irradiation program in accordance with **Table 3-4**, **Table 3-5** or **Table 3-6** respectively. The adjusted reference temperature RT_{NDTj} or RT_{T0} or RT_{T0j} thus determined may be taken for the proof of safety against brittle fracture alternatively to the value of RT_{limit} .